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(54) **SPARK PLUG**

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USPC 313/118, 143
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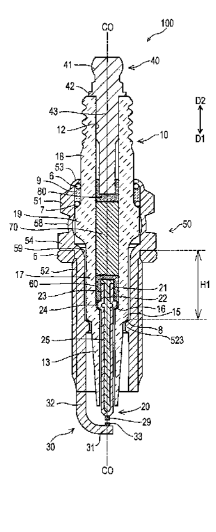
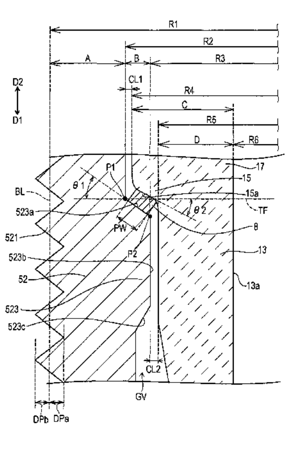
(57) **ABSTRACT**

A spark plug includes an insulator including an axial hole and having an outer periphery with a tapered outer face; a metal shell having a thread portion and a tapered inner face; and a circular packing sandwiched between the tapered outer face of the insulator and the tapered inner face of the metal shell. On at least one cross section including the axis, $(A/B)\geq 3.1$, $B\geq 0.25$, and $(A+B)\leq 2.0$ are satisfied, where A represents a length of (a difference between an effective diameter of the thread portion and an inner diameter at a rear end of the tapered inner face)/2, and B represents a length of (a difference between the inner diameter at the rear end of the tapered inner face and an inner diameter at a front end of the tapered inner face)/2.

8 Claims, 3 Drawing Sheets





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H01T 13/36	(2006.01)
H01B 3/12	(2006.01)

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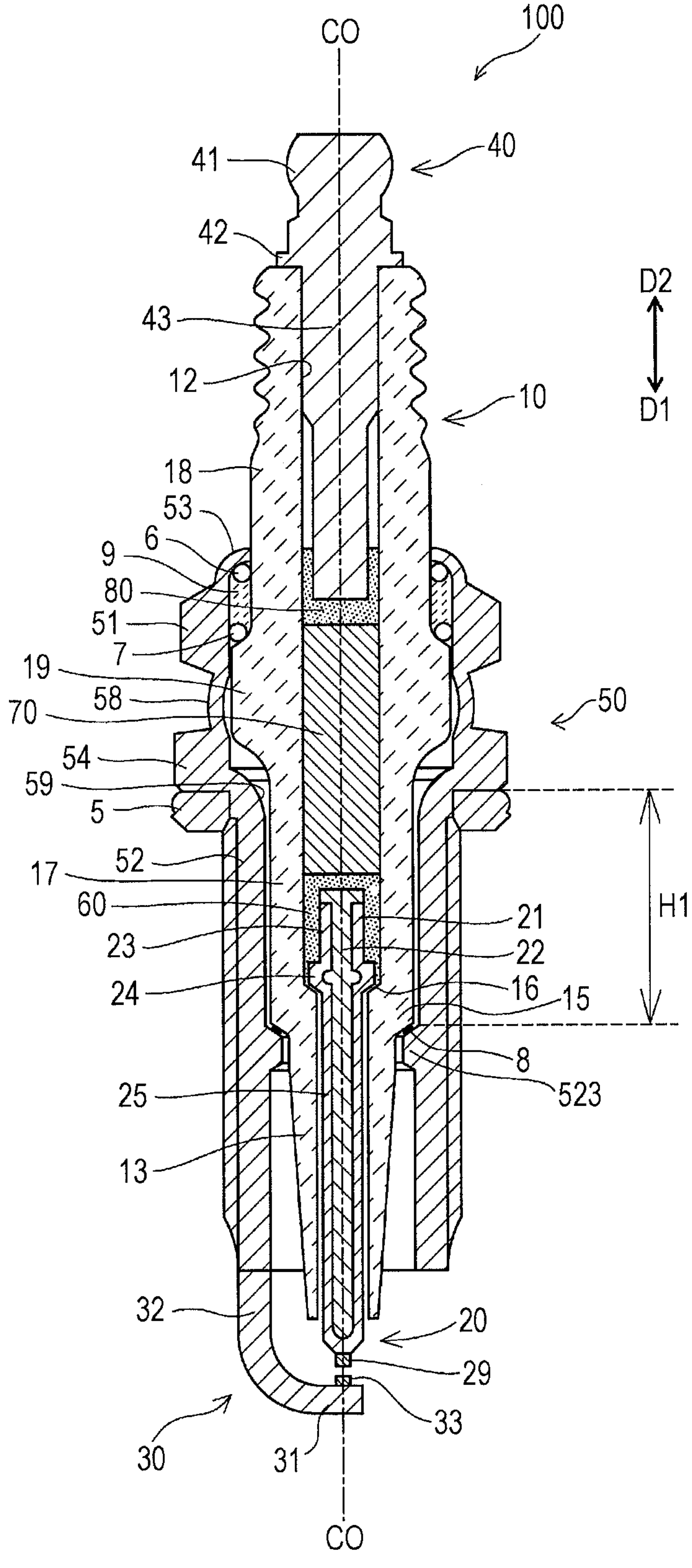
FIG. 1



CO
100
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41
42
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54
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523
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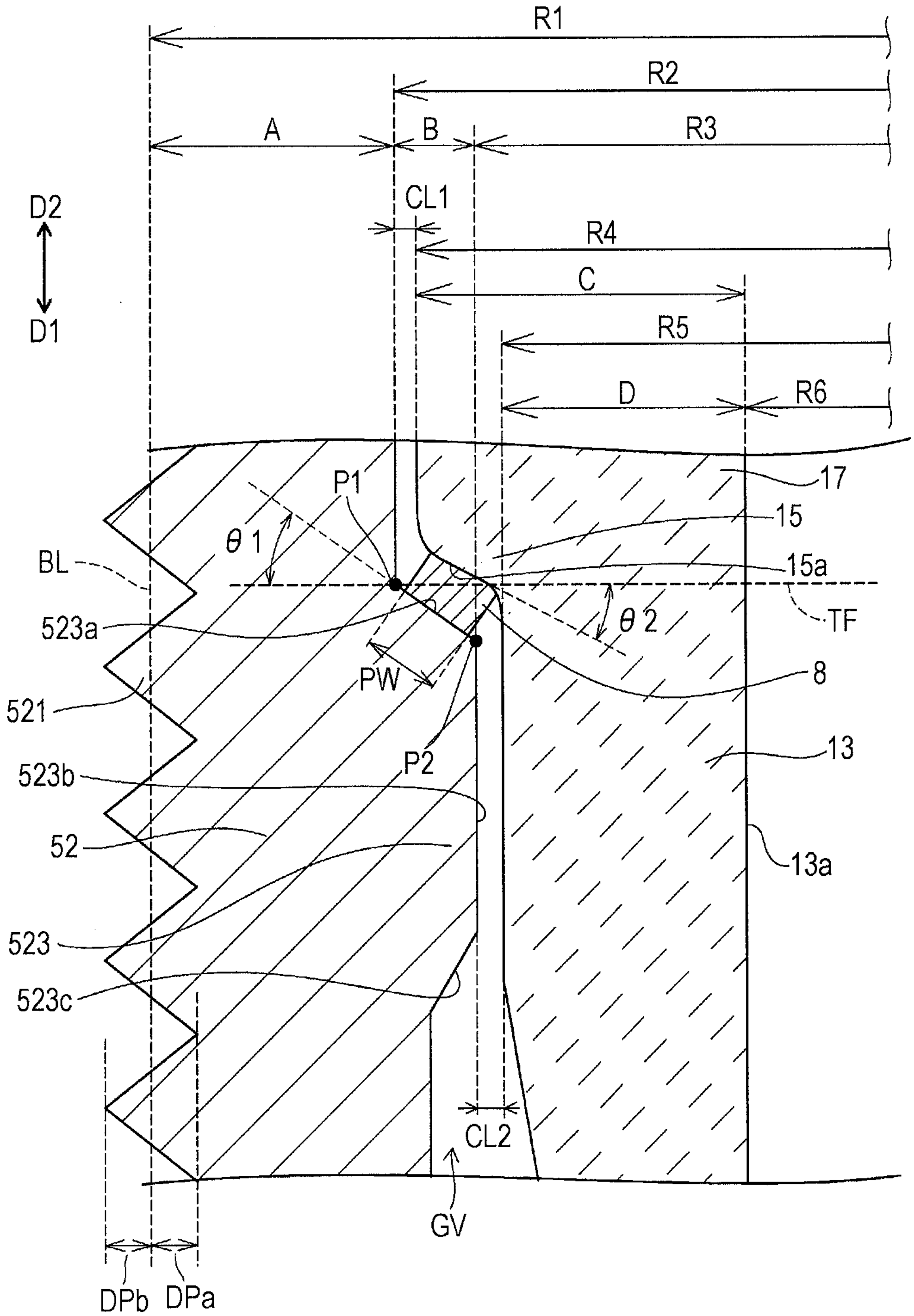
CO
D2
D1
H1

FIG. 2


R1
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CL1
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17
15
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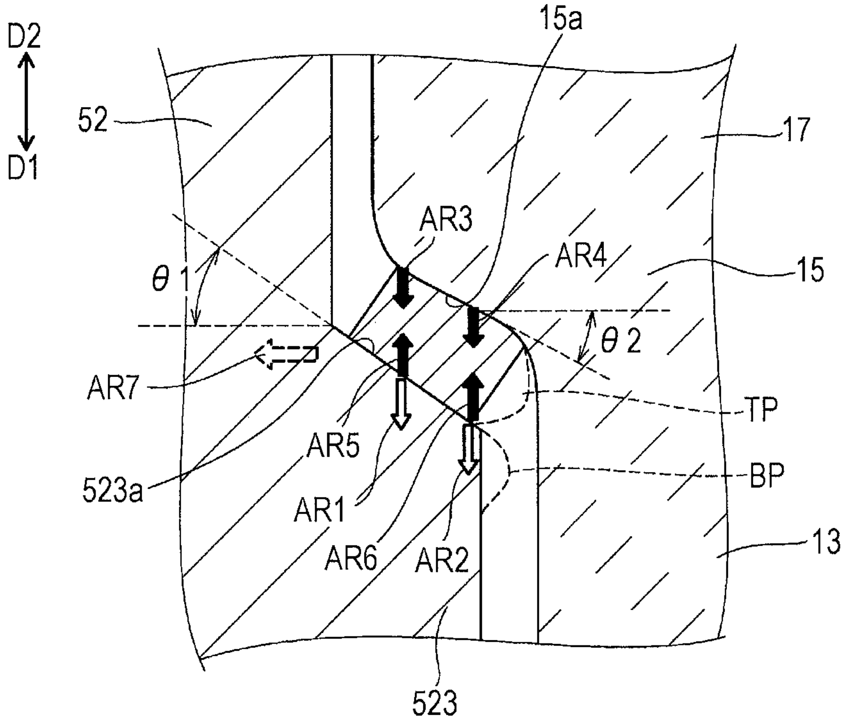
P1
θ 1
BL
TF
θ 2
523a
PW
8
521
P2
13
523b
13a
52
523
523c
CL2
GV
DPb
DPa

FIG. 3



D2
D1
52
15a
17
AR3
AR4
15
θ 1
θ 2
AR7
TP
AR5
523a
BP
AR1
AR6
AR2
13
523

SPARK PLUG

CROSS-REFERENCE TO RELATED PATENT APPLICATIONS

This application is a U.S. National Phase Application under 35 U.S.C. §371 of International Patent Application No. PCT/JP2013/004344, filed Jul. 16, 2013, and claims the benefit of Japanese Patent Applications No. 2012-158280, filed on Jul. 17, 2012, No. 2012-241478, filed Nov. 1, 2012, and No. 2013-147158, filed Jul. 15, 2013, all of which are incorporated by reference in their entirety herein. The International Application was published in Japanese on Jan. 23, 2014 as International Publication No. WO/2014/013723 under PCT Article 21(2).

FIELD OF THE INVENTION

The present invention relates to a spark plug used for ignition in an internal combustion engine and the like.

BACKGROUND OF THE INVENTION

Size reduction of a spark plug is desired for purposes such as increasing the degree of freedom in designing an internal combustion engine. For example, a spark plug with a nominal diameter of the thread of the metal shell of not more than 10 mm has been developed. On the other hand, there are increasing tendencies to desire the airtight and dielectric strength properties of spark plug due to an increase in the compression of fuel gas in internal combustion engines, and an accompanying increase in the voltage applied to the spark plug.

CITATION LIST

Patent Literatures

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Patent Document 2: Japanese Patent No. 4548818
Patent Document 3: Japanese Patent No. 4268771
Patent Document 4: Japanese Patent No. 4267855
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Problems to be Solved by the Invention

However, when the spark plug is reduced in diameter, it is often difficult to achieve both the airtight and dielectric strength properties of the spark plug due to dimensional limitations and the like.

An object of the present invention is to provide a technique to create a balance between airtight property and dielectric strength property of the spark plug can be achieved.

SUMMARY OF THE INVENTION

Solutions to the Problems

The present invention was made to solve at least some of the problem discussed above, and may be realized as the following embodiments.

Embodiment 1

A spark plug includes: a tubular insulator having an axial hole extending in a direction of an axis thereof (hereinafter, also referred to as an "axial direction"), the tubular insulator having an outer periphery with a tapered outer face where an outer diameter thereof decreases from a rear end to a front end thereof; a tubular metal shell having a through-hole extending in the axial direction through which the insulator is inserted, the tubular metal shell having a thread portion including an installation thread ridge on an outer periphery of the thread portion and a tapered inner face where an inner diameter thereof decreases from the rear end to the front end on an inner periphery of the thread portion; and a circular packing. The circular packing is sandwiched between the tapered outer face of the insulator and the tapered inner face of the metal shell for sealing the gap. The thread portion has a nominal diameter of not more than 10 mm; and at least one cross section including the axis satisfies expressions of: $(A/B) \geq 3.1$, $B \geq 0.25$, and $(A+B) \leq 2.0$. In the equations, A represents a length (mm) of (a difference between an effective diameter of the thread portion and an inner diameter at a rear end of the tapered inner face)/2, and B represents a length (mm) of (a difference between the inner diameter at the rear end of the tapered inner face and an inner diameter at a front end of the tapered inner face)/2.

The greater the length B, the more the area of the tapered inner face of the metal shell increases. Thus, the sealing load required for ensuring a contact pressure necessary for ensuring airtightness becomes large. Thus, in order to decrease the required sealing load, a relatively small length B is preferable. However, when the length B between the inner diameter at the rear end of the tapered inner face and the inner diameter at the front end of the tapered inner face is excessively small, the area of the tapered inner face of the metal shell becomes so small that possibly the tapered outer face of the insulator cannot be supported. If the tapered inner face of the metal shell cannot support the tapered outer face of the insulator, the gap between the tapered outer face of the insulator and the tapered inner face of the metal shell cannot be properly sealed, resulting in a decrease in airtightness. According to the above configuration, $B \geq 0.25$ mm is satisfied, so that the area of the tapered inner face of the metal shell can be ensured, and the insulator can be properly supported.

When the length B is excessively large, the bending moment due to the sealing load becomes large. Further, the greater the length A between the inner diameter at the rear end of the tapered inner face and the effective diameter of the thread portion, the greater the strength of the thread portion with respect to the bending moment becomes. Thus, when the ratio of the length A to the length B (A/B) is excessively small, the strength of the thread portion with respect to the bending moment is insufficient. As a result, the problem of deformation of the thread portion (such as the so-called thread elongation) could be caused. In other words, because of the small strength of the thread portion, it may become impossible to apply the required sealing load. Thus, the contact pressure necessary for ensuring airtightness may not be ensured. According to the above configuration, $(A/B) \geq 3.1$ is satisfied, whereby airtightness can be ensured while suppressing the deformation of the thread portion.

The greater the sum of the length A and the length B (A+B), the smaller the diameter of the insulator inserted into the through-hole of the metal shell becomes. Thus, if (A+B) is excessively large, it may become impossible to ensure the thickness of the insulator in the radial direction, resulting in a decrease in dielectric strength properties. According to the above configuration, because $(A+B) \leq 2.0$ mm is satisfied, the length of the insulator can be ensured, whereby the decrease in dielectric strength properties can be suppressed.

Thus, according to the above configuration, both airtight and dielectric strength properties of the spark plug can be achieved. Particularly, the airtight and dielectric strength properties of the spark plug including the thread portion with the nominal diameter of not more than 10 mm can be achieved.

Embodiment 2

The spark plug according to Embodiment 1, wherein the length A satisfies 1.23≤A≤1.54, and the length B satisfies 0.25≤B≤0.45.

According to the above configuration, by making the length A and the length B more appropriate, airtight and dielectric strength properties of the spark plug can be even more improved without causing insulator penetration or thread portion deformation.

Embodiment 3

The spark plug according to Embodiment 1 or Embodiment 2, wherein the tapered inner face of the metal shell and a plane perpendicular to the axis form an acute angle of not less than 35 degrees and not more than 50 degrees, and is greater than an acute angle formed by the tapered outer face of the insulator and the plane perpendicular to the axis.

When the acute angle (which may be referred to as the first acute angle) formed by the tapered inner face of the metal shell and the plane perpendicular to the axis is excessively small, the sealing load in the axial direction tends to become large, whereby a part of the metal shell around the radially inner side of the tapered inner face tends to be deformed. Further, when the first acute angle is not more than the acute angle (which may be referred to as the second acute angle) formed by the tapered outer face of the insulator and the plane perpendicular to the axis, a large load tends to be applied onto the radially inner part of the tapered inner face of the metal shell, so that similarly the metal shell tends to be deformed in the radially inner part of the tapered inner face. If the radially inner part of the tapered inner face of the metal shell is deformed, the part and the insulator may contact each other, possibly resulting in the problem of insulator breakage. If the first acute angle is excessively large, the sealing load tends to be increased toward the radially outer side, and deformation of the thread portion may be caused. According to the above configuration, the first acute angle is not less than 35 degrees and not more than 50 degrees and greater than the second acute angle. Thus, insulator breakage or deformation of the thread portion due to the sealing load can be suppressed.

Embodiment 4

The spark plug according to any one of Embodiments 1 to 3, wherein 15≤(E−F)≤46 is satisfied, where E (Hv) is the Vickers hardness of a portion of the metal shell in which the tapered inner face is formed, and F (Hv) is the Vickers hardness of the packing.

When the difference between the hardness E and the hardness F (E−F) is excessively large; namely, when the packing is excessively soft, the amount of deformation of the packing may become excessive, possibly resulting in insulator breakage due to deformation of the packing. When the difference between the hardness E and the hardness F (E−F) is excessively small; namely, when the packing is excessively hard, the amount of deformation of the packing may become insufficient, and an excessive load may be applied to the tapered inner face of the metal shell, possibly causing deformation of the thread portion. According to the above configuration, the difference between the hardness E and the hardness F (E−F) satisfies 15 Hv≤(E−F)≤46 Hv, whereby insulator breakage or deformation of the thread portion can be suppressed.

The present invention can be realized in various modes, such as in the form of a spark plug, or an internal combustion engine fitted with the spark plug.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features and advantages of the present invention will become more readily appreciated when considered in connection with the following detailed description and appended drawings, wherein like designations denote like elements in the various views, and wherein:

FIG. **1** is a cross sectional view of a spark plug **100** according to the present embodiment.

FIG. **2** is an enlarged cross sectional view of a portion including a shelf portion **523** of an installation thread portion **52** of a metal shell **50** and a step portion **15** of a ceramic insulator **10**.

FIG. **3** is a diagram explaining a stress loaded onto the portion including the shelf portion **523** of the installation thread portion **52** and the step portion **15** of the ceramic insulator **10**.

DETAILED DESCRIPTION OF THE INVENTION

A. Embodiment

A-1. Configuration of Spark Plug

In the following, various modes for carrying out the present invention will be described with reference to an embodiment. FIG. **1** is a cross sectional view of a spark plug **100** according to the embodiment. In FIG. **1**, the dash-dot line indicates an axis CO (which may also be referred to as an axis CO) of the spark plug **100**. A direction parallel with the axis CO (upper-lower direction in FIG. **1**) may also be referred to as the axial direction. A radial direction of a circle about the axis CO may be simply referred to as the radial direction, and a circumferential direction of the circle about the axis CO may simply be referred to as the circumferential direction. In FIG. **1**, a lower direction may be referred to as a front end direction D**1**, while an upper direction may be referred to as a rear end direction D**2**. The lower side of FIG. **1** will be referred to as the front end of the spark plug **100**, and the upper side of FIG. **1** will be referred to as the rear end of the spark plug **100**. The spark plug **100** includes a ceramic insulator **10** as an insulator, a center electrode **20**, a ground electrode **30**, a terminal metal fitting **40**, and a metal shell **50**.

The ceramic insulator **10** is formed by sintering alumina and the like. The ceramic insulator **10** is a substantially cylindrical member (tubular member) extending along the axial direction and including a through-hole **12** (axial hole) penetrating the ceramic insulator **10**. The ceramic insulator **10** includes a flange portion **19**, a rear end body portion **18**, a front end body portion **17**, a step portion **15**, and an insulator nose portion **13**. The rear end body portion **18** is located backward from the flange portion **19**, and has an outer diameter smaller than an outer diameter of the flange portion **19**. The front end body portion **17** is located forward of the flange portion **19**, and has an outer diameter smaller than the outer diameter of the rear end body portion **18**. The insulator nose portion **13** is located forward of the front end body portion **17**, and has an outer diameter smaller than the outer diameter of the front end body portion **17**. The insulator nose portion **13** has an increasingly smaller diameter toward the front end, and is exposed in the combustion chamber of an internal combustion engine (not shown) when the spark plug **100** is installed thereon. The step portion **15** is formed between the insulator nose portion **13** and the front end body portion **17**. The step portion **15** includes a tapered outer face (**15***a* in FIG. **2**) on an outer periphery thereof, with an increasingly smaller outer diameter from the rear end to the front end (as will be described in detail below).

The metal shell **50** is a substantially cylindrical member (tubular member) formed of an electrically conductive metal material (such as low carbon steel material) for fixing the spark plug **100** on the engine head (not shown) of the internal combustion engine. The metal shell **50** has a through-hole **59** penetrating the metal shell **50** along the axis CO. The metal shell **50** is disposed on the outer periphery of the ceramic insulator **10**. Namely, the insulator **10** is inserted and held within the through-hole **59** of the metal shell **50**. The front end of the ceramic insulator **10** is exposed on the front end of the metal shell **50**. The rear end of the ceramic insulator **10** is exposed on the rear end of the metal shell **50**.

The metal shell **50** includes a hexagonal-columnar tool engaging portion **51** for engaging a spark plug wrench, an installation thread portion **52** for installing on the internal combustion engine, and a flange-shaped seating portion **54** formed between the tool engaging portion **51** and the installation thread portion **52**. The installation thread portion **52** has a nominal diameter of not more than M10 (10 mm (millimeters)). For example, the nominal diameter of the installation thread portion **52** is preferably M10 or M8, and is more preferably M10.

Between the installation thread portion **52** and the seating portion **54** of the metal shell **50**, a circular gasket **5** formed of a bent metal sheet is fitted. The gasket **5** seals a gap between the spark plug **100** and the internal combustion engine (engine head) when the spark plug **100** is installed on the internal combustion engine.

The metal shell **50** further includes a thin-walled crimping portion **53** disposed on the rear end of the tool engaging portion **51**, and a thin-walled compressive deformation portion **58** disposed between the seating portion **54** and the tool engaging portion **51**. In a ringed area formed between the inner periphery of a portion of the metal shell **50** extending from the tool engaging portion **51** to the crimping portion **53** and the outer periphery of the rear end body portion **18** of the ceramic insulator **10**, circular ring members **6** and **7** are disposed. Between the two ring members **6** and **7** in this area, talc powder **9** is filled. The installation thread portion **52** of the metal shell **50** includes a shelf portion **523** protruding inwardly of the installation thread portion **52**. The shelf portion **523** includes a tapered inner face (**523***a* in FIG. **2**) on the inner periphery thereof, with an increasingly smaller outer diameter from the rear end to the front end (as will be described in detail below).

The rear end of the crimping portion **53** is bent radially inwardly and fixed onto the outer periphery of the ceramic insulator **10**. At the time of manufacturing, the compressive deformation portion **58** of the metal shell **50** is compressively deformed as the crimping portion **53** fixed onto the outer periphery of the ceramic insulator **10** is pressed toward the front end. The weight with which the crimping portion **53** is pressed toward the front end during manufacturing is referred to as a crimping load. By the compressive deformation of the compressive deformation portion **58**, the ceramic insulator **10** is pressed toward the front end within the metal shell **50** via the ring members **6** and **7** the talc **9**. As a result, the step portion **15** of the ceramic insulator **10** is pressed onto the shelf portion **523** of the metal shell **50** via the circular plate packing **8**. Namely, as will be described in detail below, a gap between the tapered outer face of the step portion **15** and the tapered inner face the shelf portion **523** is sealed via the plate packing **8**. As a result, the gas in the combustion chamber of the internal combustion engine is prevented from leaking outside via the gap between the metal shell **50** and the ceramic insulator **10** by the plate packing **8**. Preferably, in the metal shell **50**, a length H1 of not less than 14.3 mm is ensured between the front end face (which may be referred to as a seating face) of the seating portion **54** and the rear end of the shelf portion **523**.

The plate packing **8** is formed of a high thermal conductivity material, such as copper or aluminum. When the plate packing **8** has high thermal conductivity, the heat of the ceramic insulator **10** can be efficiently transmitted to the shelf portion **523** of the metal shell **50**, so that the heat conduction of the spark plug **100** is improved and thermal resistance can be increased.

The center electrode **20** is a bar-like member extending along the axis CO and inserted in the through-hole **12** of the insulator **10**. The center electrode **20** has a structure including an electrode base material **21** and a core material **22** embedded inside the electrode base material **21**. The electrode base material **21** is formed of nickel or an alloy with nickel as a principal component (such as INCONEL (registered trademark) 600). The core material **22** is formed of a material with better thermal conductivity than the alloy of the electrode base material **21**, such as copper or an alloy with copper as a principal component. The front end of the center electrode **20** is exposed on the front end of the ceramic insulator **10**.

The center electrode **20** also includes a flange portion **24** (which may be referred to as an electrode flange portion or a flanged portion) disposed at a predetermined position in the axial direction, a head portion **23** (electrode head portion) disposed on the rear end with respect to the flange portion **24**, and a nose portion **25** (electrode nose portion) disposed on the front end with respect to the flange portion **24**. The flange portion **24** is supported by a step portion **16** of the ceramic insulator **10**. At the front end portion of the nose portion **25** of the center electrode **20**, an electrode tip **29** is joined by laser welding, for example. The configuration of the front end portion of the nose portion **25** of the center electrode **20** will be described below with reference to FIGS. **2** and **3**. The electrode tip **29** is formed of a material with a high melting point noble metal as a principal component. The material of the electrode tip **29** may include iridium (Ir) or an alloy with Ir as a principal component. Specifically, Ir-5Pt alloy (an iridium alloy containing 5% by mass of platinum) and the like is often used.

The ground electrode **30** is joined to the front end of the metal shell **50**. The electrode base material of the ground electrode **30** is formed of a highly corrosion resistant metal, such as the INCONEL 600 nickel alloy. The ground electrode **30** includes a base material proximal end portion **32** that is joined to the front end face of the metal shell **50** by welding, for example. As a result, the ground electrode **30** is electrically connected to the metal shell **50**. The base material front end portion **31** of the ground electrode **30** is bent such that one side face of the base material front end portion **31** is disposed axially opposite the electrode tip **29** of the center electrode **20** on the axis CO. On the one side face of the base material front end portion **31**, an electrode tip **33** is welded at a position opposite the electrode tip **29** of the center electrode **20**. For the electrode tip **33**, Pt (platinum) or an alloy with Pt as a principal component, such as Pt-20Ir alloy (a platinum alloy containing 20% by mass of iridium) is used, for example.

Between the electrode tip **29** of the center electrode **20** and the electrode tip **33** of the ground electrode **30**, a spark gap is formed.

The terminal metal fitting **40** is a bar-like member extending along the axis CO. The terminal metal fitting **40** is formed of an electrically conductive metal material (such as low carbon steel), with a metal layer (such as a Ni layer) formed on the surface thereof by plating, for example, for corrosion prevention. The terminal metal fitting **40** includes a flange portion **42** (terminal chin portion) disposed at a predetermined position in the axial direction, a cap installing portion **41** located backward from the flange portion **42**, and a nose portion **43** (terminal nose portion) disposed on the front end with respect to the flange portion **42**. The cap installing portion **41** including the rear end of the terminal metal fitting **40** is exposed on the rear end of the ceramic insulator **10**. The nose portion **43** including the front end of the terminal metal fitting **40** is inserted (press-fitted) into the through-hole **12** of the ceramic insulator **10**. The cap installing portion **41** is configured to be fitted with a plug cap connected to a high-voltage cable (not shown) to apply a high voltage for producing a spark.

In the through-hole **12** of the ceramic insulator **10**, in an area between the front end of the terminal metal fitting **40** and the rear end of the center electrode **20**, a resistor element **70** for reducing radio interference noise at the time of spark generation is disposed. The resistor is formed of a composition including, for example, glass particles as a principal component, ceramic particles other than glass, and an electrically conductive material. A gap between the resistor element **70** and the center electrode **20** in the through-hole **12** is filled with an electrically conductive seal **60**. A gap between the resistor element **70** and the terminal metal fitting **40** is filled with an electrically conductive seal **80** of glass and metal.

A-2. Configuration of Metal Shell Around Shelf Portion of Installation Thread Portion

FIG. **2** is an enlarged cross sectional view of a portion including the shelf portion **523** of the installation thread portion **52** of the metal shell **50** and the step portion **15** of the ceramic insulator **10**. This view is that of a cross section of the spark plug **100** taken along a plane including the axis CO. On the outer periphery of the installation thread portion **52**, mounting thread ridges **521** are formed. A dashed line BL in FIG. **2** indicates a virtual outer periphery (which may also be referred to as an effective diameter defining plane BL) defining an effective diameter R**1** of the installation thread portion **52**. The effective diameter defining plane BL is a virtual outer periphery such that a root depth DPa from the root of the thread ridges **521** to the effective diameter defining plane BL is equal to a crest height DPb from the crest of the thread ridges **521** to the effective diameter defining plane BL. When the installation thread portion **52** has a nominal diameter of 10 mm, the effective diameter R**1** is approximately 9.3 mm.

The shelf portion **523** of the installation thread portion **52** includes the tapered inner face **523***a* described above, an inner side face **523***b*, and an inversely tapered inner face **523***c*. The tapered inner face **523***a* is an inner periphery of a rear end portion of the shelf portion **523** where the inner diameter thereof gradually decreases from the rear end to the front end thereof. The inversely tapered inner face **523***c* is an inner periphery of a front end portion of the shelf portion **523** where the inner diameter thereof gradually increases from the rear end to the front end thereof. The inner side face **523***b* is an inner periphery extending from the front end of the tapered inner face **523***a* to the rear end of the inversely tapered inner face **523***c*, and is parallel with the axial direction. The terms "inner diameter" and "outer diameter" as used herein each refer to a straight line segment passing through the center.

The tapered inner face **523***a* has an inner diameter R**2** at a rear end P**1**. In other words, the inner diameter R**2** may be the inner diameter of the installation thread portion **52** at a portion backward from the rear end P**1** of the shelf portion **523**. The tapered inner face **523***a* has an inner diameter R**3** at a front end P**2**. The inner diameter R**3** may be the inner diameter of the inner side face **523***b*.

A length A in the radial direction of a portion of the installation thread portion **52** backward from the rear end P**1** of the tapered inner face **523***a* may be expressed as one half of the difference between the effective diameter R**1** of the installation thread portion **52** and the inner diameter R**2** at the rear end P**1** of the tapered inner face **523***a*. Namely, the length A (FIG. **2**) can be expressed as $A=(R1-R2)/2$. The length A may also be referred to as a thread portion thickness A.

Further, a length B in the radial direction of the shelf portion **523** may be expressed as one half of the difference between the inner diameter R**2** at the rear end P**1** of the tapered inner face **523***a* and the inner diameter R**3** at the front end P**2** of the tapered inner face **523***a*. Namely, the length B (FIG. **2**) can be expressed as $B=(R2-R3)/2$. The length B may also be referred to as a shelf thickness B.

In the cross section of FIG. **2**, an acute angle formed by the tapered inner face **523***a* of the shelf portion **523** and a virtual plane TF perpendicular to the axis CO (FIG. **1**) is referred to as a first acute angle **91**.

The front end body portion **17** of the ceramic insulator **10** has an outer diameter R**4** smaller than the inner diameter R**2** by ($2\times CL1$) such that a predetermined clearance CL**1** (such as 0.05 mm to 0.45 mm) can be ensured between the front end body portion **17** and the opposite inner periphery of the metal shell **50** with the inner diameter R**2** ($R4=R2-(2\times CL1)$). An inner diameter R**6** at an inner periphery **13***a* of the through-hole **12** in the front end body portion **17** and the insulator nose portion **13** is determined in accordance with the outer diameter of the nose portion **25** (not shown in FIG. **2**) of the center electrode **20** inserted into the through-hole **12**. Preferably, the inner diameter R**6** is in a range of 1.5 mm to 1.8 mm, for example. A length C in the radial direction of the front end body portion **17** (thickness of the portion of the ceramic insulator **10**) can be expressed as one half of the difference between the outer diameter R**4** and the inner diameter R**6**. Namely, the length C (FIG. **2**) can be expressed as $C=(R4-R6)/2$.

An outer diameter R**5** of a part of the insulator nose portion **13** of the ceramic insulator **10** opposite the shelf portion **523** of the metal shell **50** is smaller than the inner diameter R**3** of the shelf portion **523** by ($2\times CL2$) such that a predetermined clearance CL**2** (such as 0.15 mm to 0.6 mm) can be ensured between the part and the shelf portion **523** of the metal shell **50** ($R5=R3-(2\times CL2)$). A length D in the radial direction of a part of the insulator nose portion **13** opposite the shelf portion **523** of the metal shell **50** (the thickness of the part of the ceramic insulator **10**) can be expressed as one half of the difference between the outer diameter R**5** and the inner diameter R**6**. Namely, the length D (FIG. **2**) can be expressed as $D=(R5-R6)/2$. The lengths C and D may also be referred to as insulation thicknesses C and D, respectively. The greater the insulation thicknesses C and D, the more the dielectric strength properties of the spark plug **100** is improved.

The step portion **15** of the ceramic insulator **10** includes the tapered outer face **15***a* on the outer periphery thereof, with an increasingly smaller outer diameter from the rear end to the front end. In the cross section of FIG. **2**, an acute angle formed by the tapered outer face **15***a* of the step portion **15** and the virtual plane TF perpendicular to the axis CO (FIG. **1**) is referred to as a second acute angle θ2. In the cross section of FIG. **2**, while the portions of the tapered outer face **15***a* around the front and rear ends are curved, the central portion between the curves at the front and rear ends is linear. The second acute angle θ2 is determined based on the linear part of the central portion.

The circular plate packing **8** sandwiched between the tapered inner face **523***a* of the shelf portion **523** and the tapered outer face **15***a* of the step portion **15** of the ceramic insulator **10** is compressed in the axial direction by the sealing load corresponding to the crimping load, as described above. The plate packing **8** is compressively deformed by the sealing load along the tapered inner face **523***a*. In the cross section of FIG. **2**, a width PW in a direction along the tapered inner face **523***a* is approximately 100% of the linear length of the tapered inner face **523***a* in the cross section of FIG. **2**, for example, and may preferably be in a range of 0.38 mm to 0.86 mm.

A-3: First Evaluation Test

In a first evaluation test, eleven kinds of samples of the spark plug **100** with the nominal diameter of the installation thread portion **52** of 10 mm were used. In the eleven kinds of samples, the metal shell **50** had various thread portion thicknesses A and shelf thicknesses B.

In the first evaluation test, a crimping test and a dielectric strength test were conducted. In the crimping test, the metal shell **50** was crimped by using 34 kN (kilo newton) of crimping load, and the presence or absence of the problem of the step portion **15** of the ceramic insulator **10** slipping from the shelf portion **523** of the metal shell **50** toward the front end (which may be hereafter referred to as slipping), and the presence or absence of the problem of the thread ridges **521** of the installation thread portion **52** of the metal shell **50** being deformed (which may hereafter be referred to as thread elongation) were tested. The presence or absence of slipping can be visually confirmed, while the presence or absence of thread elongation can be confirmed by using a thread gauge. When neither thread elongation nor slipping was present, the sample was evaluated as "Good". When either thread elongation or slipping was present, the sample was evaluated as "Poor".

In the dielectric strength test, the samples in which the ground electrode **30** was not bent toward the front end of the center electrode **20** were used so that no discharge was produced between the electrode tip **33** of the ground electrode **30** and the electrode tip **29** of the center electrode **20**. Further, in these samples, a space GV between the metal shell **50** and the ceramic insulator **10** on the front end with respect to the plate packing **8** was filled with an insulating fluid so that no discharge was produced between the center electrode **20** and the ground electrode **30**. A voltage was applied between the terminal metal fitting **40** and the metal shell **50** of the samples, and the applied voltage was increased until insulator penetration (dielectric breakdown) was caused. When the voltage at which insulator penetration occurred (which is referred to as a penetration voltage) was 25 kV (kilovolts) or higher, the sample was evaluated as "Good". When the penetration voltage was lower than 25 kV, the sample was evaluated as "Poor". The evaluation results are shown in Table 1. In Table 1, the unit of the thread portion thickness A and the shelf thickness B is millimeters.

TABLE 1

Sample No.	A	B	A/B	A + B	Crimping test	Dielectric strength test
1-1	1.30	0.20	6.5	1.50	Poor (Slipping)	Good
1-2	1.23	0.25	4.9	1.48	Good	Good
1-3	1.38	0.40	3.5	1.78	Good	Good
1-4	1.53	0.25	6.1	1.78	Good	Good
1-5	1.38	0.45	3.1	1.83	Good	Good
1-6	1.13	0.50	2.3	1.63	Poor (Thread extension)	Good
1-7	1.28	0.30	4.3	1.58	Good	Good
1-8	1.28	0.45	2.9	1.73	Poor (Thread extension)	Good
1-9	1.54	0.45	3.4	1.99	Good	Good
1-10	1.60	0.40	4.0	2.00	Good	Good
1-11	1.70	0.40	4.1	2.10	Good	Poor

It can be seen from the test results shown in Table 1 that no slipping was caused in the samples (1-2) to (1-11) with the shelf thickness B of not less than 0.25 mm, while slipping was caused in the sample (1-1) with the shelf thickness B of less than 0.25 mm. It is thought that when the shelf thickness B is less than 0.25 mm, the area of the tapered inner face **523***a* of the metal shell **50** is so small that the tapered outer face **15***a* of the ceramic insulator **10** cannot be supported. When the tapered inner face **523***a* of the metal shell **50** cannot support the tapered outer face **15***a* of the ceramic insulator **10**, the gap between the tapered outer face **15***a* of the ceramic insulator **10** and the tapered inner face **523***a* of the metal shell **50** cannot be properly sealed, resulting in a decrease in airtightness. Thus, it is seen from the test results that it is preferable to ensure the shelf thickness B of not less than 0.25.

Further, it is seen that no thread elongation was caused in the samples (1-1) to (1-5), (1-7), and (1-9) to (1-11) with the ratio of the thread portion thickness A to the shelf thickness B (A/B) of not less than 3.1, while thread elongation was caused in the samples (1-6) and (1-8) with the ratio (A/B) of less than 3.1. This is presumably due to the following reasons.

FIG. **3** is a diagram explaining the stress loaded onto a portion including the shelf portion **523** of the installation thread portion **52** and the step portion **15** of the ceramic insulator **10**. By the crimping load, the shelf portion **523** is subjected to stress toward the front end, as indicated by white arrows AR**1** and AR**2** in FIG. **3**. The greater the shelf thickness B, the greater the bending moment that would bend the installation thread portion **52** in the radial direction based on the stress. Also, the greater the thread portion thickness A, the greater the strength of the installation thread portion **52** with respect to the bending moment. Thus, it is thought that, when the ratio (A/B) is less than 3.1, the strength of the installation thread portion **52** with respect to the bending moment is insufficient, resulting in the problem of deformation of the installation thread portion **52**, specifically the development of thread elongation, for example. In other words, it is possible that the necessary crimping load cannot be applied due to the lack of strength of the installation thread portion **52**, so that the contact pressure required for ensuring airtightness cannot be obtained. Accordingly, the ratio (A/B) is preferably not less than 3.1 .

Further, in the samples (1-1) to (1-10) with the sum of the thread portion thickness A and the shelf thickness B (A+B) of not more than 2.0 mm, the evaluation of the dielectric strength test was "Good", while in the sample (1-11) with (A+B) exceeding 2.0 mm, the dielectric strength test evaluation was "Poor". This is presumably due to the following reasons.

For example, when the nominal diameter of the installation thread portion **52** is a fixed value (such as 10 mm), the greater A or (A+B), the smaller the inner diameter R3 of the shelf portion **523** of the metal shell **50** becomes. Then, the insulation thicknesses C and D (FIG. **2**) of the ceramic insulator **10** are decreased. As a result, the insulation thicknesses C and D of the ceramic insulator **10** cannot be ensured, and the dielectric strength properties may be decreased. When (A+B) is greater than 2.0 mm, therefore, A or (A+B) is excessively large and therefore the insulation thickness C or D is excessively small, resulting in a decrease in dielectric strength properties. Thus, it is clear that (A+B) is preferably less than 2.0 mm.

Further, when (A+B) is excessively large, the shelf thickness B may become large even when the ratio (A/B) is not less than 3.1, resulting in an increase in the area of the tapered inner face **523***a*. As a result, the area of the tapered inner face **523***a* may become so large that, in order to ensure the required sealing pressure (the load per unit area) between the tapered inner face **523***a* and the plate packing **8**, the crimping load may need to be increased. From this viewpoint too, a relatively small (A+B) is preferable.

Thus, from the test results of the first evaluation test (Table 1), the thread portion thickness A and the shelf thickness B preferably satisfy $(A/B) \geq 3.1$, $B \geq 0.25$, and $(A+B) \leq 2.0$. In this way, both dielectric strength property and airtightness can be achieved in the spark plug **100**.

As will be seen from the above description, the differences between the samples in the test results of the evaluation test are presumably due mainly to the differences in the thread portion thickness A and the shelf thickness B. Thus, the above preferable ranges of the thread portion thickness A and the shelf thickness B are presumed to be applicable regardless of the configuration other than the thread portion thickness A and the shelf thickness B.

A-4: Second Evaluation Test

In a second evaluation test, six kinds of samples satisfying the preferable ranges clarified by the first evaluation test were prepared, and the crimping test and the dielectric strength test were conducted under even more strict conditions than in the first evaluation test. Namely, in the second evaluation test, six kinds of samples of the spark plug **100** with the nominal diameter of the installation thread portion **52** of 10 mm were used. In these six kinds of samples, the metal shell **50** had various thread portion thicknesses A and shelf thicknesses B.

In the crimping test according to the second evaluation test, the metal shell **50** of each sample was crimped by using 36 kN of crimping load. The evaluation method was the same as for the crimping test according to the first evaluation test.

In the dielectric strength test according to the second evaluation test, a test similar to the dielectric strength test according to the first evaluation test was conducted. In the second evaluation test, when the penetration voltage was 30 kV (kilovolts) or higher, the sample was evaluated to be "Good". When the penetration voltage was lower than 30 kV, the sample was evaluated to be "Poor". The evaluation results are shown in Table 2. In Table 2, the unit of the thread portion thickness A and the shelf thickness B is millimeters.

TABLE 2

Sample No.	A	B	Crimping test	Dielectric strength test
2-1	1.15	0.35	Poor (Thread extension)	Good
2-2	1.23	0.30	Good	Good
2-3	1.38	0.35	Good	Good
2-4	1.50	0.45	Good	Good
2-5	1.54	0.35	Good	Good
2-6	1.60	0.40	Good	Poor

From the test results shown in Table 2, it is seen that no thread elongation was caused in the sample (2-2) to (2-6) with the thread portion thickness A of not less than 1.23 mm, while thread elongation was caused in the sample (2-1) with the thread portion thickness A of less than 1.23 mm. It is thought that when the thread portion thickness A is less than 1.23 mm in the case of the crimping load of the second evaluation test, the thread portion thickness A is so small that the strength of the installation thread portion **52** with respect to the bending moment is insufficient, resulting in thread elongation. Accordingly, from the test results, the thread portion thickness A is preferably not less than 1.23 mm.

Further, it is seen that in the samples (2-1) to (2-5) with the thread portion thickness A of not more than 1.54 mm, the dielectric strength test evaluation was "Good", while in the sample (2-6) with the thread portion thickness A exceeding 1.54 mm, the dielectric strength test evaluation was "Poor". This is presumably due to the fact that, when the thread portion thickness A exceeds 1.54 mm, the insulation thicknesses C and D (FIG. **2**) cannot be ensured, resulting in a decrease in dielectric strength property. Thus, it is more preferable that the thread portion thickness A is not more than 1.54 mm.

From the test results shown in Table 2, it is seen that as long as the thread portion thickness A is not less than 1.23 mm and not more than 1.54 mm, the shelf thickness B may have any value between 0.30 or more and 0.45 mm or less. Thus, the differences in the evaluation results in the second test are thought to be mainly due to the thread portion thickness A.

While it has been clarified from the first evaluation test that preferably $(A/B) \geq 3.1$, $B \geq 0.25$, and $(A+B) \leq 2.0$, it will be understood that solving the three inequalities with respect to B yields $0.25 \leq B \leq$ about 0.48. It is thought that from this inequality and the test results shown in Table 2, the shelf thickness B may preferably be in a range of at least $0.25 \leq B \leq 0.45$.

Thus, from the test results of the second evaluation test (Table 2), it is more preferable that the thread portion thickness A and the shelf thickness B satisfy 1.23 mm$\leq A \leq$1.54 mm and $0.25 \leq B \leq 0.45$, respectively. In this way, in the spark plug **100**, both dielectric strength property and airtightness can be satisfied at higher level. Namely, by further making the length A and the length B appropriate, the airtight and dielectric strength properties of the spark plug can be even more improved without causing insulator penetration or thread portion deformation.

For example, it is particularly preferable that, in the spark plug **100** with the nominal diameter of the installation thread portion **52** of 10 mm (effective diameter R**1**=9.268 mm), the thread portion thickness A=1.41 mm and the shelf thickness B=0.43 mm. In this way, the outer diameter R**4** of the front end body portion **17** of the ceramic insulator **10** (FIG. **2**) is 6.25 mm, and the inner diameter R**3** at the front end P**2** of the tapered inner face **523***a* (inner diameter of the inner side face **523***b* of the shelf portion **523**) (FIG. **2**) is 5.6 mm. Thus, airtight and dielectric strength properties of the spark plug **100** can be sufficiently achieved.

A-5: Third Evaluation Test

In a third evaluation test, five kinds of samples satisfying the more preferable ranges clarified by the second evaluation test were prepared, and the crimping test was conducted with even more strict conditions than in the second evaluation test. Namely, in the third evaluation test, five kinds of samples of the spark plug **100** with the nominal diameter of the installation thread portion **52** of 10 mm, the thread portion thickness A=1.38 mm, and the shelf thickness B=0.35 mm were used. In these five kinds of samples, the second acute angle θ2 was fixed at 30 degrees, and the first acute angle θ1 was set at different angles.

The first acute angle θ1 was set to be greater than the second acute angle θ2 (θ1>θ2). It is obvious, without even performing a test, that θ1>θ2 is more preferable than θ1≤θ2, as described below.

As shown in FIG. **3**, when θ1≤θ2, the interval between the tapered inner face **523***a* of the shelf portion **523** and the tapered outer face **15***a* of the ceramic insulator **10** becomes narrower toward the radially inner side. As a result, the compressive force at the radially inner side portion of the plate packing **8** (see arrows AR**4** and AR**6** in FIG. **3**) becomes greater than the compressive force at the radially outer side portion of the plate packing **8** (see arrows AR**3** and AR**5** in FIG. **3**). Thus, the plate packing **8** may be deformed and protrude into the radially inner side (see a dashed line TP in FIG. **3**), possibly damaging the ceramic insulator **10**. The same can be said of the stress applied to the tapered inner face **523***a* (see arrows AR**1** and AR**2** in FIG. **3**). Namely, the stress applied to the radially inner side portion of the tapered inner face **523***a* (arrow AR**2** in FIG. **3**) becomes greater than the stress applied to the radially outer side portion of the tapered inner face **523***a* (arrow AR**1** in FIG. **3**). As a result, the shelf portion **523** is deformed in such a manner as to protrude into the radially inner side (see a dashed line BP in FIG. **3**), possibly damaging the ceramic insulator **10**. Thus, the first acute angle θ1 is preferably set to be greater than the second acute angle θ2 (θ1>θ2).

In the crimping test of the third evaluation test, the metal shell **50** of each sample was crimped by using 38 kN of crimping load. Then, the presence or absence of thread elongation in the sample, and the presence or absence of breakage of the ceramic insulator **10** after crimping were evaluated. The presence or absence of thread elongation was confirmed by using a thread gauge. The presence or absence of breakage in the ceramic insulator **10** was visually confirmed after applying red checking liquid to the ceramic insulator **10** for visualizing breakage. The evaluation results are shown in Table 3. In Table 3, "Good" indicates the absence of thread elongation or breakage in the ceramic insulator **10**, and "Poor" indicates the presence of thread elongation or breakage in the ceramic insulator **10**.

TABLE 3

Sample No.	θ1	θ2	Thread extension	Insulator breakage
3-1	31	30	Good	Poor
3-2	35	30	Good	Good
3-3	40	30	Good	Good
3-4	50	30	Good	Good
3-5	54	30	Poor	Good

In the test results shown in Table 3, no breakage in the ceramic insulator **10** was caused in the samples (3-2) to (3-5) with the first acute angle θ1 of 35 degrees or more, while insulator breakage was caused in the sample (3-1) with the first acute angle θ1 of less than 35 degrees. In the samples (3-1) to (3-4) with the first acute angle θ1 of not more than 50, no thread elongation was caused, while in the sample (3-5) with the first acute angle θ1 exceeding 50 degrees, thread elongation was caused. These are presumably due to the following reasons.

The stress applied to the shelf portion **523** based on the crimping load can be resolved into a component parallel to the axial direction (arrows AR**1** and AR**2** in FIG. **3**), and a component perpendicular to the axis (arrow AR**7** in FIG. **3**). The smaller the first acute angle θ1, the greater the component parallel to the axial direction becomes. The greater the first acute angle θ1, the greater the component perpendicular to the axis becomes.

When the first acute angle θ1 is less than 35 degrees, the component parallel to the axis (arrows AR**1** and AR**2** in FIG. **3**) becomes too large. As a result, the shelf portion **523** may be deformed in such a manner as to protrude toward the radially inner side (see the dashed line BP in FIG. **3**), damaging the ceramic insulator **10**. Thus, when the first acute angle θ1 is less than 35 degrees, the breakage was caused in the insulator **10**.

When the θ1 exceeds 50 degrees, the component perpendicular to the axis (arrow AR**7** in FIG. **3**) becomes too large. As a result, the force that would bend the installation thread portion **52** is increased, causing deformation of the installation thread portion **52**. Thus, the first acute angle θ1 of over 50 degrees could probably lead to deform the installation thread portion **52**, thereby causing thread elongation.

Therefore, the first acute angle θ1 is preferably greater than the second acute angle θ2 and in a range of not less than 35 degrees and not more than 50 degrees. In this way, in the spark plug **100**, airtight and dielectric strength properties can be achieved at higher level. Namely, by making the first acute angle θ1 more appropriate, the airtight and dielectric strength properties of the spark plug can be even more improved without causing insulator penetration or thread portion deformation.

A-6: Fourth Evaluation Test

In the fourth evaluation test, seven kinds of samples satisfying the more preferable ranges clarified by the third evaluation test were prepared, and the crimping test was conducted with even more strict conditions than in the third evaluation test. Specifically, in the fourth evaluation test, samples of the spark plug **100** with the nominal diameter of the installation thread portion **52** of 10 mm, the thread portion thickness A=1.38 mm, the shelf thickness B=0.35 mm, the first acute angle θ1=35 degrees, and θ2=30 degrees were used. The seven kinds of samples were prepared by varying the material of the metal shell **50** and the material of the plate packing **8** such that the shelf portion **523** and the plate packing **8** had different hardness E and F. The material of the metal shell **50** was low carbon steel, of which the hardness can be modified by varying the amount of carbon or heat treatment conditions. The material of the plate packing **8** was an alloy with copper or aluminum as a principal component, of which the hardness can be modified by varying the amount of added element or heat treatment conditions.

In the crimping test of the fourth evaluation test, the metal shell **50** of each sample was crimped by using 40 kN of crimping load. Then, the presence or absence of thread elongation in the sample after crimping, and the presence or absence of breakage in the ceramic insulator **10** were evaluated by the same method as in the third evaluation test. The evaluation results are shown in Table 4. In Table 4, "Good" indicates the absence of thread elongation or breakage, while "Poor" indicates the presence of thread elongation or breakage.

Further, in a cross section of each sample taken in a plane including the axis CO, Vickers hardness (Hv) was measured by the Vickers hardness test with measuring load of 1.961 N according to the JIS Z2244 standard. The plate packing **8** was measured at one location corresponding to substantially the central point in the cross section. The shelf portion **523** of the metal shell **50** was measured at three locations in the cross section at substantially equal intervals and 0.1 mm away from the tapered inner face **523***a*. The number of measurements taken in the cross section was five per each kind of sample. Average values of the measurement values were taken to provide hardness E and F of each sample. The evaluation results are shown in Table 4.

TABLE 4

Sample No.	E	F	E-F	Thread extension	Insulator breakage
4-1	132	122	10	Poor	Good
4-2	137	122	15	Good	Good
4-3	140	121	19	Good	Good
4-4	152	120	32	Good	Good
4-5	160	120	40	Good	Good
4-6	164	118	46	Good	Good
4-7	169	119	50	Good	Poor

In the test results shown in Table 4, no thread elongation is caused in the samples (4-2) to (4-7) with the difference between the hardness E of the shelf portion **523** and the hardness F of the plate packing **8** (E−F) of not less than 15 Hv, while thread elongation is caused in the sample (4-1) with the difference (E−F) of less than 15 Hv. In the samples (4-1) to (4-6) with the difference (E−F) of not more than 46 Hv, no breakage is caused in the ceramic insulator **10**, while breakage is caused in the ceramic insulator **10** in the sample (4-7) with the difference (E−F) exceeding 46 Hv. This is presumably due to the following reasons.

When the difference (E−F) exceeds 46 Hv; namely, when the plate packing **8** is excessively soft with respect to the shelf portion **523**, the amount of deformation of the plate packing **8** is excessive, and the deformed plate packing **8** protrudes toward the ceramic insulator **10** (see the dashed line TP in FIG. **3**). As a result, the protruding plate packing **8** contacts the ceramic insulator **10**, thus causing breakage in the ceramic insulator **10**. When the difference (E−F) is less than 15 Hv; namely, when the plate packing **8** is excessively hard with respect to the shelf portion **523**, the amount of deformation of the plate packing **8** is insufficient, and excessive load is applied to the tapered inner face **523***a* of the shelf portion **523**. As a result, the installation thread portion **52** is deformed, causing thread elongation.

Thus, from the test results of the fourth evaluation test (Table 4), it is more preferable that the difference between hardness E and hardness F (E−F) satisfies 15 Hv≤(E−F)≤46 Hv. In this way, airtight and dielectric strength properties can be achieved at higher level in the spark plug **100**. Namely, by making the hardness E of the shelf portion **523** and the hardness F of the plate packing **8** more appropriate, the airtight and dielectric strength properties of the spark plug can be further improved without causing insulator breakage or thread portion deformations.

B. Modification

(1) In the above embodiment, the inner side face **523***b* of the shelf portion **523** is parallel with the axis CO. However, the shelf portion **523** may have an increasingly greater inner diameter from the rear end to the front end, as in the inversely tapered inner face **523***c* of the shelf portion **523**. In this case, too, the shelf thickness B of the shelf portion **523** is determined by the inner diameter R**3** at the front end P**2** of the tapered inner face **523***a*. Similarly, while the inner periphery on the rear end with respect to the shelf portion **523** of the installation thread portion **52** is parallel with the axis CO, the inner diameter may be increased from the rear end to the front end. In this case, too, the thread portion thickness A of the installation thread portion **52** or the shelf thickness B of the shelf portion **523** is determined by the inner diameter R**2** at the rear end P**1** of the tapered inner face **523***a*.

(2) In the cross section of FIG. **2**, the tapered inner face **523***a* is linear along its entire length. However, the tapered inner face **523***a* may be curved around the front and rear ends, as in the tapered outer face **15***a*. In this case, the first acute angle θ1 formed by the tapered inner face **523***a* of the shelf portion **523** and the plane TF perpendicular to the axis CO is determined by the linear central portion between the front end curve and the rear end curve.

(3) The improvements in airtight and dielectric strength properties of the spark plug **100** according to the embodiment are considered due to parameters concerning the shelf portion **523** of the metal shell **50** and nearby configuration elements (such as the plate packing **8** and the ceramic insulator **10**); namely, due to the thread portion thickness A, the shelf thickness B, the first acute angle θ1, the second acute angle θ2, and the Vickers hardness E and F. Thus, the elements other than these parameters, such as the material of the metal shell **50** and the material of the plate packing **8**, may be variously modified. For example, the material of the metal shell **50** may be nickel-plated low carbon steel, or low carbon steel without nickel plating. The material of the plate packing **8** may include copper, aluminum, iron, zinc, or various alloys containing these elements as a principal component.

(4) The foregoing embodiment has been described with reference to an example configuration of the spark plug. However, the embodiment is merely an example and may be variously modified in accordance with the purpose or required performance of the spark plug. For example, instead of the longitudinal discharge type of spark plug that discharges in the axial direction, the invention may be configured, as a lateral discharge type of spark plug that discharges in a direction perpendicular to the axial direction.

While the present invention has been described with reference to the embodiment and the modification, the description of the embodiment is intended to aid an understanding of the present invention and not to limit the present invention. Various modifications and improvements may be made in the present invention without departing from the spirit of the invention and the scope of the claims, and the present invention includes equivalents thereof.

DESCRIPTION OF REFERENCE SIGNS

5 Gasket
6 Ring member
8 Plate packing
9 Talc
10 Ceramic insulator
12 Through-hole
13 Insulator nose portion
15 Step portion
15*a* Tapered outer face
16 Step portion
17 Front end body portion

18 Rear end body portion
19 Flange portion
20 Center electrode
21 Electrode base material
22 Core material
23 Head portion
24 Flange portion
25 Nose portion
29 Electrode tip
30 Ground electrode
31 Base material front end portion
32 Base material proximal end portion
33 Electrode tip
40 Terminal metal fitting
41 Cap installing portion
42 Flange portion
43 Nose portion
50 Metal shell
51 Tool engaging portion
52 Installation thread portion
53 Crimping portion
54 Seating portion
58 Compressive deformation portion
59 Through-hole
60 Electrically conductive seal
70 Resistor element
80 Electrically conductive seal
100 Spark plug
521 Thread ridges
523 Shelf portion
523*a* Tapered inner face
523*b* Inner side face
523*c* Inversely tapered inner face

The invention claimed is:

1. A spark plug comprising:

a tubular insulator having an axial hole extending in a direction of an axis thereof, the tubular insulator having an outer periphery with a tapered outer face where an outer diameter thereof decreases from a rear end to a front end thereof;

a tubular metal shell having a through-hole extending in the axial direction through which the insulator is inserted, the tubular metal shell having a thread portion including an installation thread ridge on an outer periphery of the thread portion and a tapered inner face where an inner diameter thereof decreases from the rear end to the front end on an inner periphery of the thread portion; and

a circular packing, which is sandwiched between the tapered outer face of the insulator and the tapered inner face of the metal shell to seal a gap therebetween, wherein:

the thread portion has a nominal diameter of not more than 10 mm; and

on at least one cross section including the axis, relationships $(A/B) \geq 3.1$, $B \geq 0.25$, and $(A+B) \leq 2.0$ are satisfied, where A represents a length (mm) of (a difference between an effective diameter of the thread portion and an inner diameter at a rear end of the tapered inner face)/2, and B represents a length (mm) of (a difference between the inner diameter at the rear end of the tapered inner face and an inner diameter at a front end of the tapered inner face)/2.

2. The spark plug according to claim **1**, wherein:

the length A satisfies $1.23 \leq A \leq 1.54$; and

the length B satisfies $0.25 \leq B \leq 0.45$.

3. The spark plug according to claim **1**, wherein

the tapered inner face of the metal shell and a plane perpendicular to the axis form an acute angle of not less than 35 degrees and not more than 50 degrees, and is greater than an acute angle formed by the tapered outer face of the insulator and the plane perpendicular to the axis.

4. The spark plug according to claim **1**, wherein

a relationship $15 \leq (E-F) \leq 46$ is satisfied, where E (Hv) is the Vickers hardness of a portion of the metal shell in which the tapered inner face is formed, and F (Hv) is the Vickers hardness of the packing.

5. The spark plug according to claim **2**, wherein

the tapered inner face of the metal shell and a plane perpendicular to the axis form an acute angle of not less than 35 degrees and not more than 50 degrees, and is greater than an acute angle formed by the tapered outer face of the insulator and the plane perpendicular to the axis.

6. The spark plug according to claim **2**, wherein

a relationship $15 \leq (E-F) \leq 46$ is satisfied, where E (Hv) is the Vickers hardness of a portion of the metal shell in which the tapered inner face is formed, and F (Hv) is the Vickers hardness of the packing.

7. The spark plug according to claim **3**, wherein

a relationship $15 \leq (E-F) \leq 46$ is satisfied, where E (Hv) is the Vickers hardness of a portion of the metal shell in which the tapered inner face is formed, and F (Hv) is the Vickers hardness of the packing.

8. The spark plug according to claim **5**, wherein

a relationship $15 \leq (E-F) \leq 46$ is satisfied, where E (Hv) is the Vickers hardness of a portion of the metal shell in which the tapered inner face is formed, and F (Hv) is the Vickers hardness of the packing.

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